OPERATING AND ENVIRONMENTAL CHARACTERISTICS OF SIGMA TAU HYDROGEN MASERS USED IN THE VERY LONG BASELINE ARRAY(VLBA)*

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Abstract

This paper presents the results obtained from performance evaluation of a pair of Sigma Tau Standards Corporation, Model VLBA–112, active hydrogen maser frequency standards. These masers were manufactured for the National Radio Astronomy Observatory (NRAO), for use on the Very Long Baseline Array (VLBA) project, and were furnished to the Jet Propulsion Laboratory (JPL) for the purpose of these tests.

Tests on the two masers were performed in the JPL Frequency Standards Laboratory (FSL), and included the characterization of output frequency stability versus environmental factors such as temperature, humidity, magnetic field and barometric pressure. The performance tests also included the determination of phase noise and Allan Variance using both FSL and Sigma Tau masers as references. All tests were conducted under controlled laboratory conditions, with only the desired environmental and operational parameters varied to determine sensitivity to external environment.

INTRODUCTION

Purpose:

The tests described herein were performed by the Jet Propulsion Laboratory (JPL) at the request of the National Radio Astronomy Observatory (NRAO). JPL was chosen for this evaluation because of its unique testing capability and facilities, and in order to provide an independent evaluation of Sigma Tau hydrogen maser performance.

All tests were conducted at JPL in the Frequency Standards Research Laboratory Test Facility in Pasadena, California, between March and September 1988.

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Sigma Tau Hydrogen Masers:

The Model VLBA–112 is a compact and ruggedized active hydrogen maser manufactured by the Sigma Tau Corporation for NRAO for use on the Very Large Baseline Array (VLBA) Project. The essential physical and electrical characteristics, as given by the manufacturer, are outlined in Table 1 below:

Table 1.
Physical and Electrical Characteristics:

Size:	Height	107cm (42 inches)
	Width	46cm (18 inches)
	Depth	76cm (30 inches)
Weight:	238kg (525 lbs)	
Input Power:	AC 115V ±10% rms, 50–60 Hz, 140 Watts	
	DC 24 to 28 V, 4 Amp. (typ.)	
	Built–in Standby Battery Supply	
Outputs:	100 MHz (2 ea.), 1 ±0.3V rms	
	10 MHz (1 ea.), ≈0.5V rms	
	5 MHz (2 ea.), 1 ±0.3V rms	

Prior to performance and environmental testing, the critical operating parameters of each of the two masers, identified as Serial Numbers 2 and 3, were determined and recorded as follows in Table 2.

Table 2.
Operating Characteristics:

Parameter	S/N 2	S/N 3
Output Power:	–100 dBm	–100 dBm
Line Q:	1.82×10^9	1.64×10^9
Cavity Loaded Q:	33,000	37,800
Coupling Factor:	0.35	0.30
Rx Noise Figure:	< 1 dB	< 1 dB
Zeeman Frequency:	827.7 Hz	808.9 Hz

Note: All tests were performed in the AUTOTUNE mode.

Test Facilities:

The JPL Frequency Standards Laboratory is responsible for the research, development and implementation of a wide variety of state–of–the–art frequency generation and distribution equipment used within the Deep Space Network (DSN). In order to achieve the demanding performance and reliability requirements, a substantial amount of assembly and subassembly testing is required. Toward this end, an extensive testing capability has been developed which includes special equipment, facilties, procedures and personnel skilled in the testing and characterization of precision oscillators and other signal sources.

The stability and environmental tests which are routinely performed, in this facility, are as follows:

1. Allan Variance
2. Spectral Density of Phase
3. Temperature Sensitivity
4. Humidity Sensitivity
5. Barometric Pressure Sensitivity
6. Magnetic Field Sensitivity

The instrumentation and test area has approximately 2,700 square feet of floor space, and houses the necessary instrumentation and test equipment. Additionally, two active hydrogen maser frequency references are conveniently located in this area. All critical equipment as well as the units under test are powered by an uninterruptable power source. The entire test area, as well as the environmental control system is backed up by an automatically switched motor generator. Temperature control is maintained to within ±0.05 degrees Centigrade through the use of a doubly redundant air conditioning system. Magnetic field variations are minimized by the use of non–magnetic construction materials throughout the facility. As an additional precaution, one of the reference hydrogen masers is housed in a magnetically shielded enclosure.

Environmental testing capability is provided by three Tenny Corporation environmental test chambers. Each chamber includes 64 square feet of floor space and is approximately 10 feet high, providing adequate space for equipment under test as well as required cables and peripherals.

The environmental testing capabilities are as shown in Table 3 below:

Table 3.
Environmental Test Capability

Parameter	Range
Temperature	15 to 35 deg. C ±0.05 deg.
Pressure	±24 inches of water ±0.5 inches.
Relative Humidity	11 to 90% RH ±5%
Magnetic Field	±0.5 Gauss

Measurement System

Figure 1 is a block diagram of the measurement system used to determine frequency stability and the Allan variance (deviation) between the Sigma Tau masers and the laboratory reference masers. Figure 2 is a block diagram of the measurement system used to determine the spectral density of phase of the two Sigma Tau masers at the 5, 10 and 100 MHz outputs.

TEST RESULTS

Sequence of Tests:

The tests and test limits are as follows in Table 4:

Table 4.
Test Sequence and Limits

Parameter	Range
Allan Variance	
Spectral Density of Phase	
Temperature	17 to 27 Deg. C
Humidity	20 to 80% RH
Barometric Pressure	±24 inches of water
Magnetic Field	±0.5 Gauss
Power Supply Variations	24 to 28 VDC

Allan Variance and Spectral Density of Phase Tests:

Figures 3, 4 and 5 are plots of the Allan Variance between the two Sigma Tau masers, and also between each of the Sigma Tau masers and one of the laboratory reference masers which serve to verify near equal performance of the two Sigma Tau masers. Included in Figure 2 is the measurement system noise floor. Figures 6, 7 and 8 are plots of the spectral density of phase between the two Sigma Tau masers at the 5, 10 and 100 MHz outputs. The spurious signals seen in each of the plots is predominantly the result of the autotuner modulation signal with some additional contribution from power supply noise.

Environmental Tests:

The purpose of these tests was to characterize each maser in terms of frequency shift for a given change in environmental condition. In each test, the output frequency was carefully monitored while one of the environmental conditions was varied as specified in Table 4. The results of each of these environmental tests is itemized below:

1. Output Frequency vs Temperature Tests — The masers were individually placed in the test chamber and the chamber temperature was cycled between 17 and 27 °C, the resultant variation in output frequency was plotted. The frequency sensitivity as a function ambient temperature is shown in Figure 9.

2. Output Frequency vs Relative Humidity Tests — With the chamber temperature held constant, the chamber relative humidity was cycled between 20 and 80% , with a 48 hour stabilization period at each limit. The observed variations in output frequency vs the relative humidity were well below 1×10^{-14}.

3. Barometric Pressure Tests — No output frequency variations were observed as the masers were individually subjected to barometric pressures of 24 inches of water above and below ambient pressure with a two hour dwell at each extreme.

4. Magnetic Field Sensitivity Tests — In order to determine the maser magnetic field sensitivity, a large (90 inch) Helmholtz coil was placed around the maser. The coil was positioned to provide a vertical magnetic field and was centered around the maser physics unit. Since the magnetic shielding effectiveness is dependent upon the magnitude of the magnetic field, the sensitivity was measured at three different field values. The magnetic field sensitivity of each maser is shown in Table 5 below:

Table 5.
Magnetic Field Sensitivity

Field	S/N 2	S/N 3
Small Field (± 0.1 G)	-1.42×10^{-13}/ Gauss	-4.74×10^{-13}/ Gauss
Medium Field (± 0.25 G)	-1.05×10^{-13}/ Gauss	-3.98×10^{-13}/ Gauss
Large Field (± 0.5 G)	-8.04×10^{-14}/ Gauss	-3.17×10^{-13}/ Gauss

5. Output Frequency vs Power Supply Variations — With the internal battery supply disconnected, the input DC voltage was varied between 24 to 28 VDC. No output frequency shift was observed as a result of these supply variations.

SUMMARY

A summary of the environmental sensitivities of the two Sigma Tau masers is presented in Table 6 below:

Table 6.
Environmental Sensitivity Summary

Condition	S/N 2	S/N 3
Temperature (17 to 27 °C)	1.37×10^{-14}/°C	4.2×10^{-14}/°C
Humidity (20 to 80% RH)	$< 1 \times 10^{-14}$	$< 1 \times 10^{-14}$
Barometric Pressure (±24 in. Water)	$< 1 \times 10^{-14}$	$< 1 \times 10^{-14}$
Magnetic Field (± 0.1 Gauss)	-1.42×10^{-13}/Gauss	-4.74×10^{-13}/Gauss
Power Supply Variations (24 to 28 VDC)	$< 1 \times 10^{-14}$	$< 1 \times 10^{-14}$

Throughout the test series the Sigma Tau performed reliably, and were well behaved. Of particular interest is the fact that both masers were transported from Soccoro, NM to Pasadena, CA, a distance of some 800 miles, in the back of a carryall van. Only a minimum of protection from shock and

vibration was provided during transit, and upon arrival both masers were within normal operating parameters.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the generous contributions of several individuals to this effort. In particular, that of Albert Kirk and Bill Deiner of JPL for their assistance in the performance of the many tests. Additionally, the generous technical assistance of Harry Peters of the Sigma Tau Corp. during the initial setup and preparation for testing is gratefully acknowledged.

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[4] Sydnor, R., "Phase Noise Test Procedures," Jet Propulsion Laboratory Internal Document, (Nov. 1988).

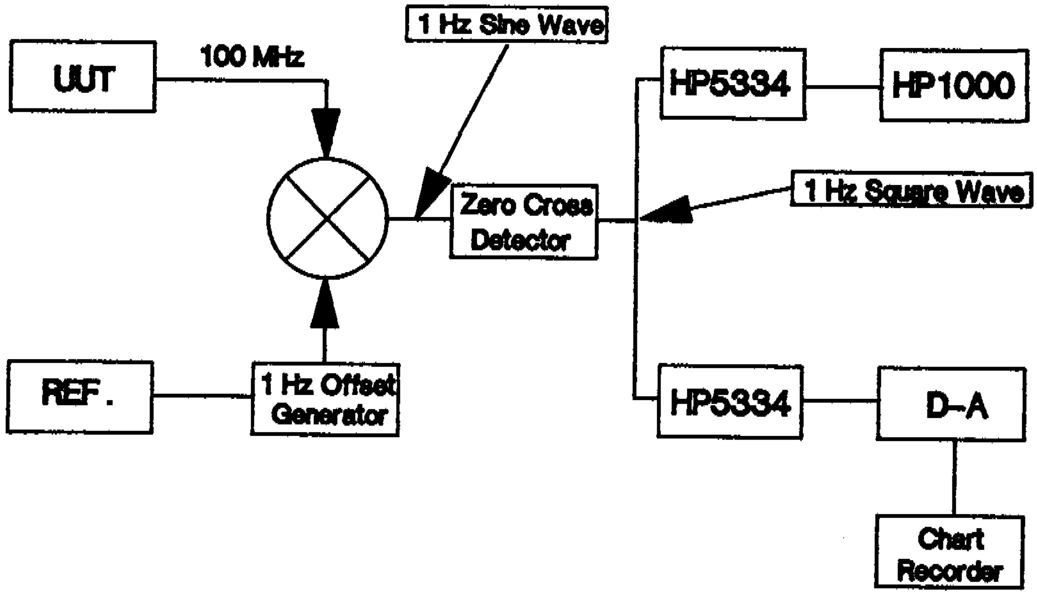

Figure 1. Measurement System for Frequency Shift & Allan Variance

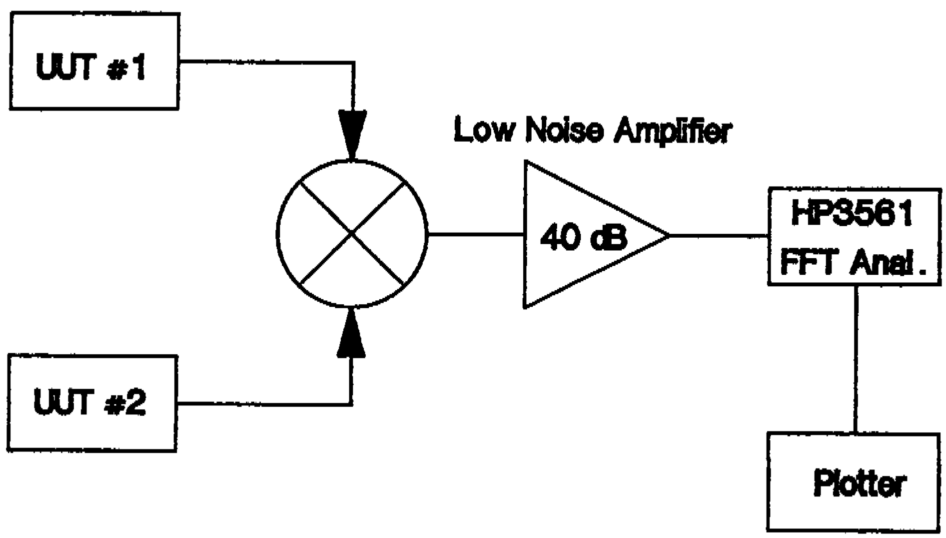

Figure 2. Phase Noise Measurement System

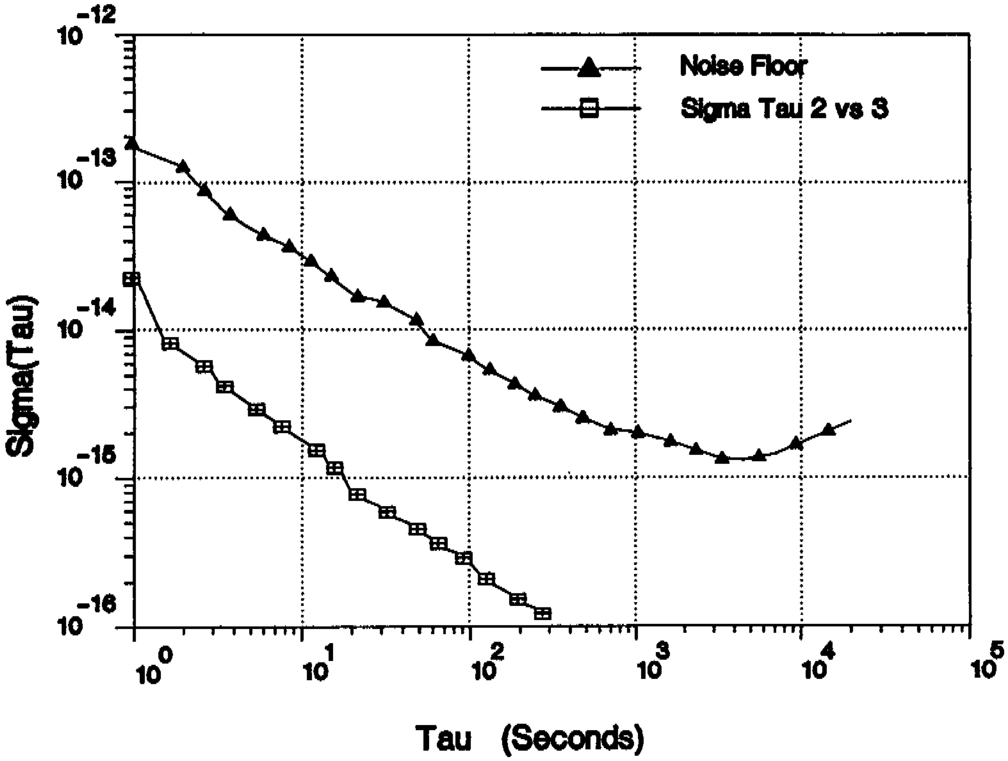

Figure 3. Allan Variance - Sigma Tau 2 vs 3

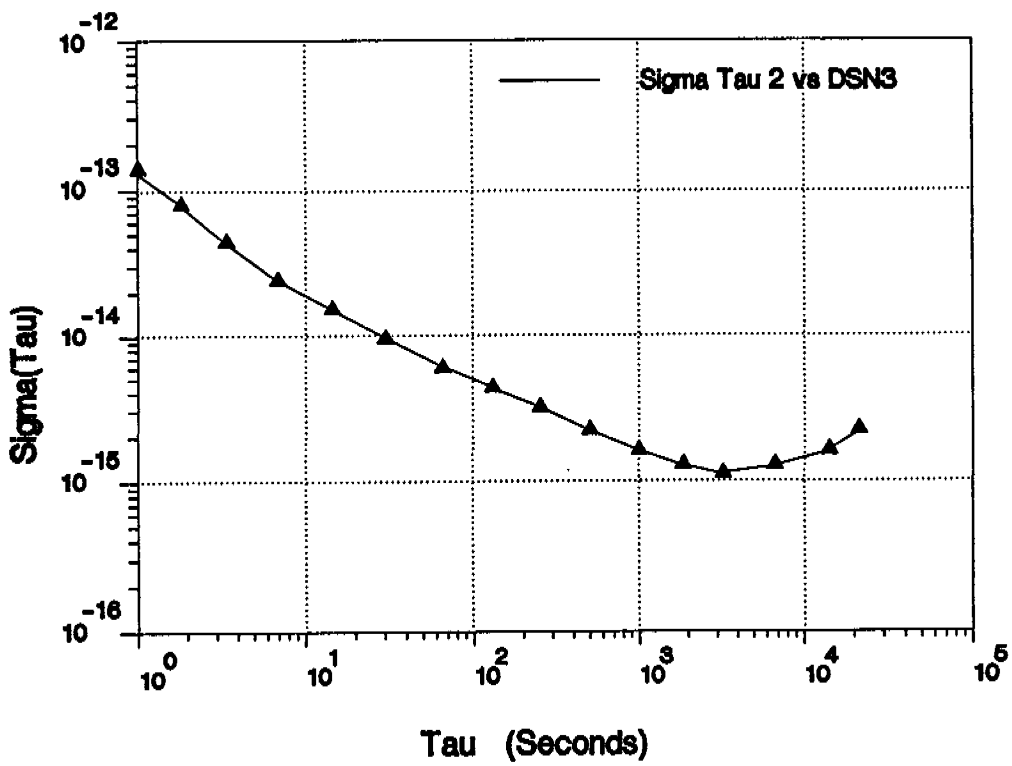

Figure 4. Allan Variance - Sigma Tau 2 vs Ref.

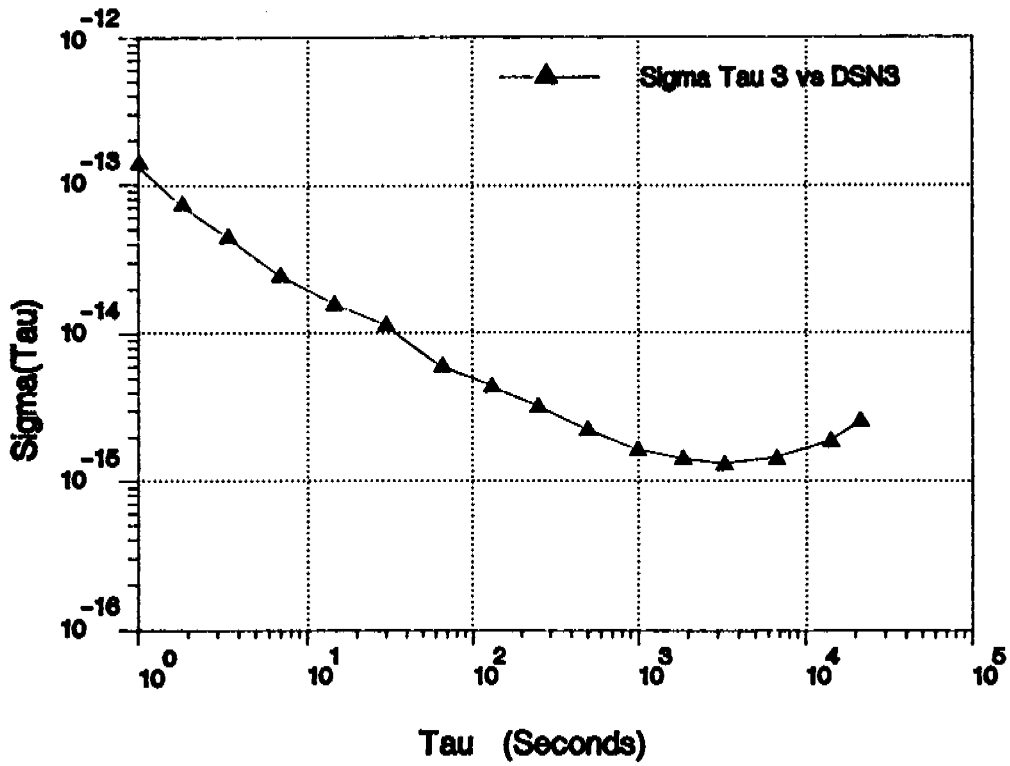

Figure 5. Allan Variance - Sigma Tau 3 vs Ref.

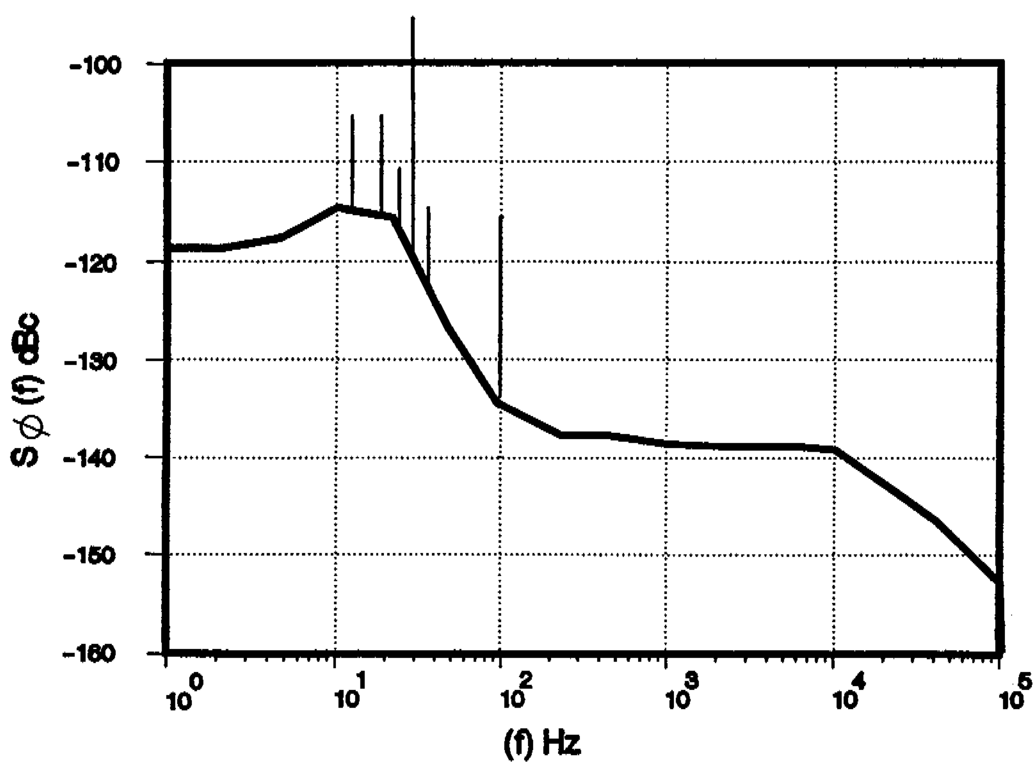

Figure 6. Phase Noise at 5 MHz Outputs

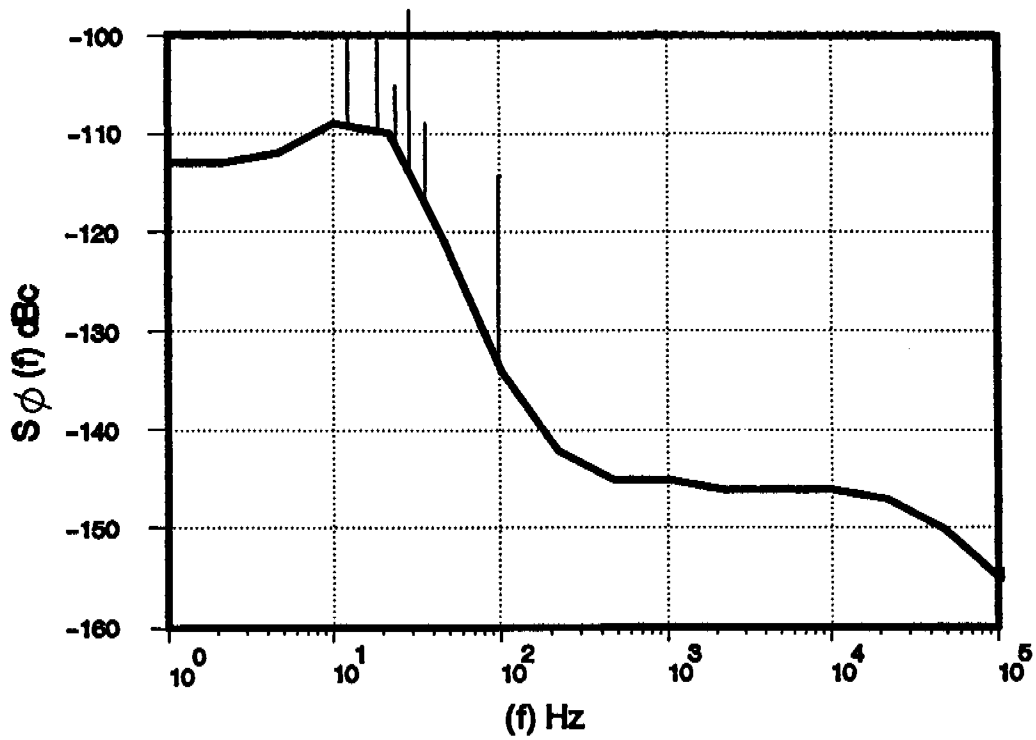

Figure 7. Phase Noise at 10 MHz Outputs

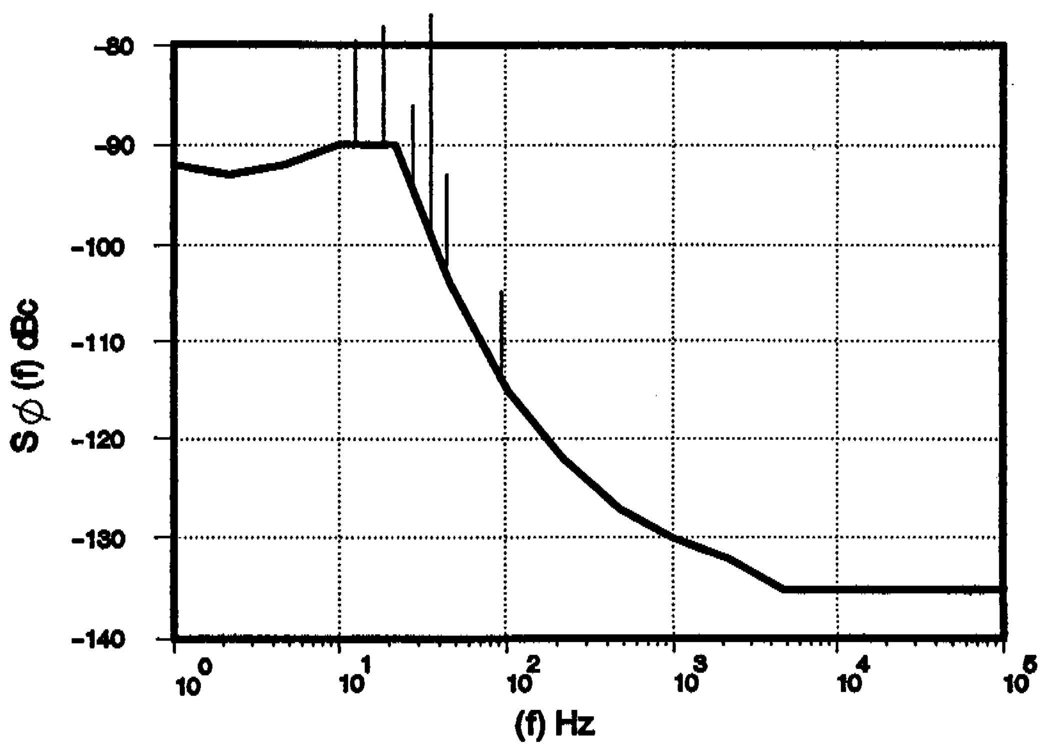

Figure 8. Phase Noise at 100 MHz Outputs

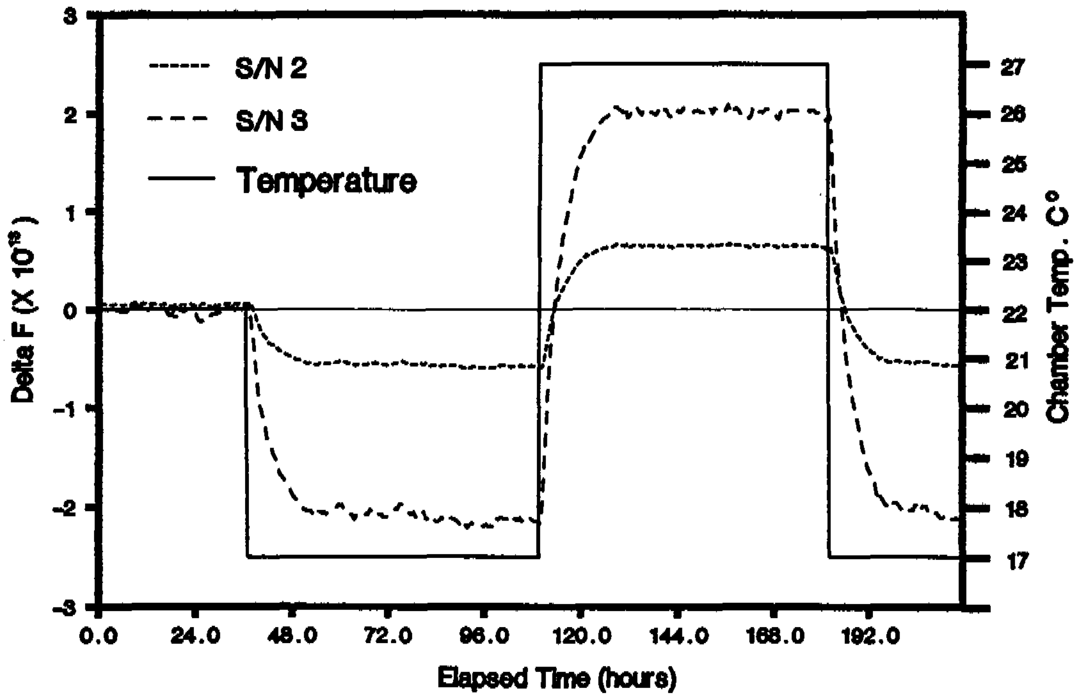

Figure 9. Output Frequency vs Temperature

QUESTIONS AND ANSWERS

HARRY PETERS, SIGMA TAU CORPORATION: I just thought that I would mention that the magnetic tests for ± 0.1 gauss and ± 1.0 gauss–it is sort of characteristic of magnetic shields that the hysteresis affect inherent in shielding is such that, for lower values of the ambient field change, you would expect larger shielding factors. However, the practical importance goes down because, if you look at the actual shift of parts in ten to the fourteenth, the shift is nearly the same as for the high field shift. We did have trouble with the early masers with the shields, but I hope that we are overcoming that.

MR. TUCKER: Yes, we were forewarned by you that one maser did have a little worse shielding than the other one.